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EVALUATION OF SIMULATED RADIOFREQUENCY HEATING PROCEDURES.(U)

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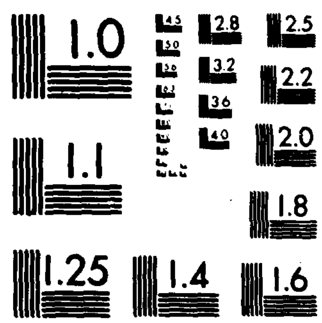

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Report SAM-TR-80-30

EVALUATION OF SIMULATED RADIOFREQUENCY HEATING PROCEDURES

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October 1980

Interim Report for Period 1 July 1978 - 1 June 1979

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

NOTICES

This interim report was submitted by personnel of the Radiation Physics Branch, Radiation Sciences Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7757-01-56.

The animals involved in this study were procured, maintained, and used in accordance with the Animal Welfare Act of 1970 and the "Guide for the Care and Use of Laboratory Animals" prepared by the Institute of Laboratory Animal Resources - National Research Council.

This technical report has been reviewed and is approved for publication.

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A method for simulating radiofrequency radiation (RFR) heating at 1.2 GHz E-field oriented in the rat using warm moist (90% relative humidity) air is presented. The method can adequately simulate the overall linear rate of internal heating in the rat and the peak temperature excursion but fails to simulate the initial rapid rate of temperature rise due to RFR. Even with this shortcoming it appears that this moist heat simulation is superior to previous hot air simulations.

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EVALUATION OF SIMULATED RADIOFREQUENCY HEATING PROCEDURES

INTRODUCTION

Radiofrequency radiation (RFR) bioeffects research is concerned with the determination of the possible harmful effects from absorption of RFR by biological objects. Since the primary end product of RFR power absorption in biological tissues is heating (1) and it is known that heating alone can produce biological effects, it is important to be able to control for those effects which are thermally induced. This can best be determined by being able to perform accurate thermal controls for each RFR exposure, i.e., simulation of RFR-produced temporal and spatial heating by other means.

The RFR heating in living tissues is a complex phenomenon because of the nonuniform internal deposition of RFR energy and the numerous heat dissipation and redistribution capabilities of the animal. Under normal environmental conditions the tissue temperature in a living animal is maintained within a narrow physiological range by thermoregulatory processes, such as, conduction, convection, evaporative heat loss, radiative heat loss or gain, and peripheral vasomotor activity (2). Under excessive external or internal heat load the normal thermoregulatory mechanisms are incapable of removing the total heat gain, and consequently the animal's colonic temperature will rise. For low RFR power levels the additional heat load can be balanced by thermoregulatory mechanisms with a resultant steady state elevated internal temperature, but for high RFR power levels the animal cannot regulate the heat load and the internal body temperature continues to rise until the RFR source is removed or the animal dies.

Attempts have been made to simulate this RFR-induced heating by using hot air exposures (3), hot water exposures (4), and infrared radiation exposures (5), but none of these methods have proved satisfactory. A modification of the hot air method of heat simulation utilizing moist heating (high relative humidity) is presented here. Placing an animal in an environment which is warmer than its normal body temperature and high in relative humidity effectively disables the animal's normal thermoregulatory processes. The animal cannot cool itself by evaporation, convection, conduction, or radiative heat loss and consequently will heat itself internally due to the generation of metabolic heat.

MATERIALS AND METHODS

RFR Exposures

All RFR exposures were performed at 1.2 GHz, continuous wave (CW), 10, 20, 40, and 80 mW/cm^2, far field, in a 5 x 2.5 x 2 m anechoic chamber (Emerson and Cummins, Inc.) using a Cober Electronics, Inc., Model 1326 RF power source with standard gain horn. The incident power density measurements were made at the location where the experimental animal was to be

placed with a Narda Microwave Corp. Model 8316 Broad Band Isotropic RF Monitor with Model 8323 probe. RF power was brought to operating level as rapidly as possible (2 sec) and monitored continuously using a Hewlett-Packard HP 432 Power Meter. The anechoic chamber temperature was maintained at 23 ± 1°C and 50 ± 10% relative humidity (RH).

White male Sprague-Dawley rats weighing between 75 and 270 g were used. Rats, restrained in well-ventilated cylindrical Plexiglas holders with a temperature probe inserted 2 cm into the rectum, were held in the anechoic chamber for 10 minutes to normalize their internal temperatures and then exposed to 10, 20, 40, or 80 mW/cm^2 for 30 min or until the rectal temperature reached 43.5°C. All rats were exposed with the long axis of their body parallel to the E-field. Rats were reused in these experiments but only after a 1-week rest period to preclude acclimatization to the heat stress. Table 1 shows the sample sizes for the RFR exposures used in this study.

TABLE 1. SAMPLE SIZE FOR EXPOSED GROUPS

Group	Exposure		Sample size
RF	10 mW/cm^2		35
	20		37[a]
	40		28[a]
	80		52[a]
		Total	152
Moist heat	34°C		34
	37		21
	38		25
	39		35[a]
	40		18
	42		31
	43		38[a]
	44		38
	45		19
	47		39[a]
	48		40
	49		50
	50		31
		Total	419

[a]Data plotted in Figures 2,3.

Moist Heat Exposures

Moist heat exposures were performed in a "Vapor-Temp"-controlled relative humidity chamber, Model VP-100At-1, manufactured by Blue M. Electric Company, at 90% relative humidity and 34°, 37°, 38°, 39°, 40°, 42°, 43°, 44°,

45°, 47°, 48°, 49°, and 50°C dry bulb temperature. Ninety percent relative humidity was chosen for this study based on several preliminary experiments which revealed that below 80% RH there was little effect on heating rate and above 95% RH there was a large variability in heating rates. Rats were restrained in Plexiglas cylinders, had a rectal temperature probe inserted, were held at room temperature for 10 min to normalize internal temperature, and then were placed one at a time in the previously stabilized humidity chamber for 30 min or until the rectal temperature reached 43.5°C. Rats which were reused were also given a 1-week rest period.

Temperature Measuring System

Rectal temperature measurements in the moist heat experiments were performed using a Yellow Springs Instrument Company Telethermometer, Model 42, with a Model 402 Thermistor Temperature probe with output connected to a Perkin-Elmer strip-chart recorder. The rectal temperature measurements in the RFR experiments were performed using a locally constructed nonperturbing thermistor temperature probe of 2 mm diameter, which utilized a thermistor sensing element with twin high impedance plastic leads connected to a Data Precision Model 3500 Digital Multimeter (resistance measurement proportional to temperature of thermistor), Microwave Labs ML 1200 Scanner, and Hewlett-Packard HP 9830A Computing Calculator with hard copy. All temperature monitoring devices were calibrated before use against a glass mercury thermometer traceable to the National Bureau of Standards (NBS) with accuracy of ± 0.05°C.

Data Analysis

The rate of heating in °C/min due to RFR or moist heat was determined by taking the slope from the best straight-line fit of the data from the strip-chart recordings (moist heat) and the HP 9830A hard copy printout (RFR). The computed slopes were checked by a second individual to insure unbiased results. The data were analyzed by the Data Sciences Division using SAS (Statistical Analysis System) linear regression techniques to determine if a relationship existed between the rate of heating (dependent variable), body weight, and power density (RF exposures) or humidity chamber dry bulb temperature (moist heat exposures). Multiple correlation coefficients (R values), measuring the closeness with which the regression plane fits the observed slopes, were determined using various factors in the linear regression analysis to empirically determine a model which adequately described the data. The selected model for each relationship was then calculated. The relationship between the RF heating slopes, weight, and power density could then be equated to the relationship between moist heat slope, weight, and chamber dry bulb temperature, the final result being an equation and series of curves allowing the calculation of the dry bulb temperature at 90% RH which could be used to simulate a particular RF power density.

RESULTS AND DISCUSSION

The results of typical temperature profiles for both RFR and moist heat exposures are shown in Figure 1. The RFR heating curve at 1.2 GHz, CW, far-field, 40 mW/cm^2, on a 200-g rat shows a rapid initial rise in temperature followed by a linear temperature rise until the termination of exposure. This initial phase is most probably due to the time lag between initial deposition of energy and the response of the biological system to that stress. The heating profile for a 200 g rat at 90% RH and 42°C shows a lag in temperature rise initially followed by a linear heating rate until the termination of exposure. Therefore, with the exception of the initial non-linear period, it is possible to simulate RFR heating by moist heating at 90% RH with the proper selection of dry bulb temperature, enabling one to match the rate of rise and maximum value of colonic temperature achieved during RFR exposure. It appears, however, that the initial rate of temperature rise cannot be simulated. This rapid initial rise in temperature, although short in duration and small compared to the total temperature rise, should not be ignored. It may very well be a significant biological factor which requires further investigation.

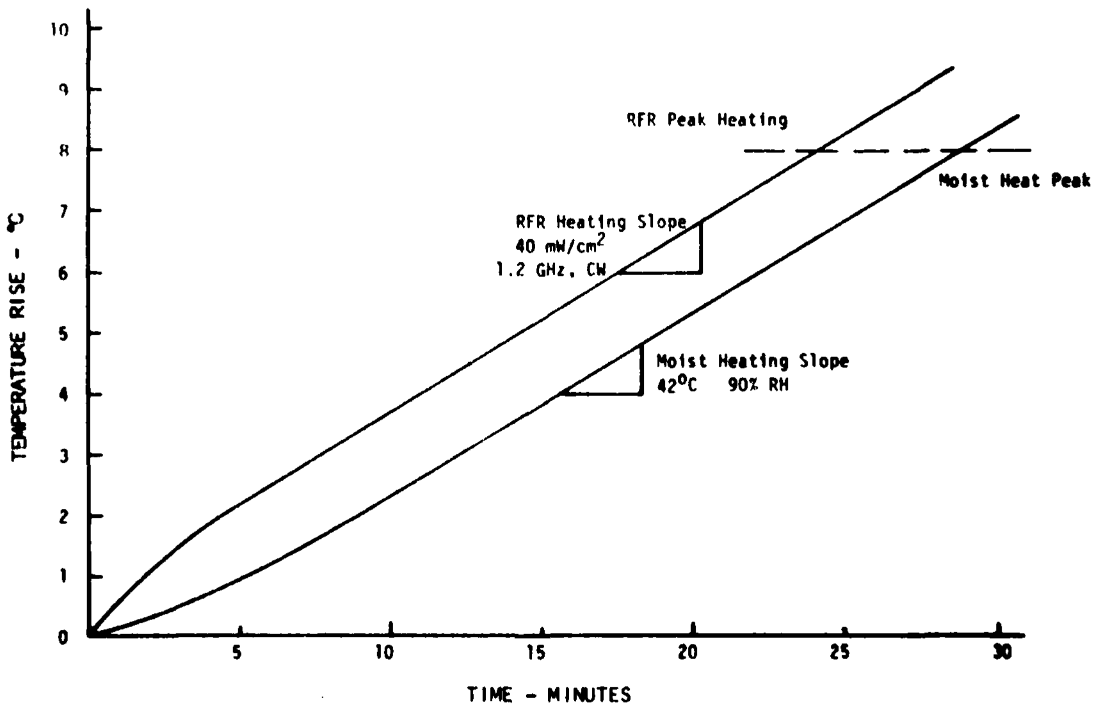

Figure 1. Typical RFR and moist heating profiles for a 200-g rat.

The results of the RFR and moist heat exposures are shown in Tables 2-3, Figure 2 (RFR), and Figure 3 (moist heat). Note that only a portion of the data is plotted for purposes of clarity. The results of the statistical analysis are shown in Table 4. The R-values calculated for each set of data were used to empirically determine a model which adequately described the data. The resultant relationship between RF slope, weight and power and moist heat slope, weight and dry bulb temperature are shown. The calculated linear model for the RFR data appears to provide a better fit to the data than the moist heat data, possibly because of a larger variability in the moist heat data or less data points at the extremes for moist heating.

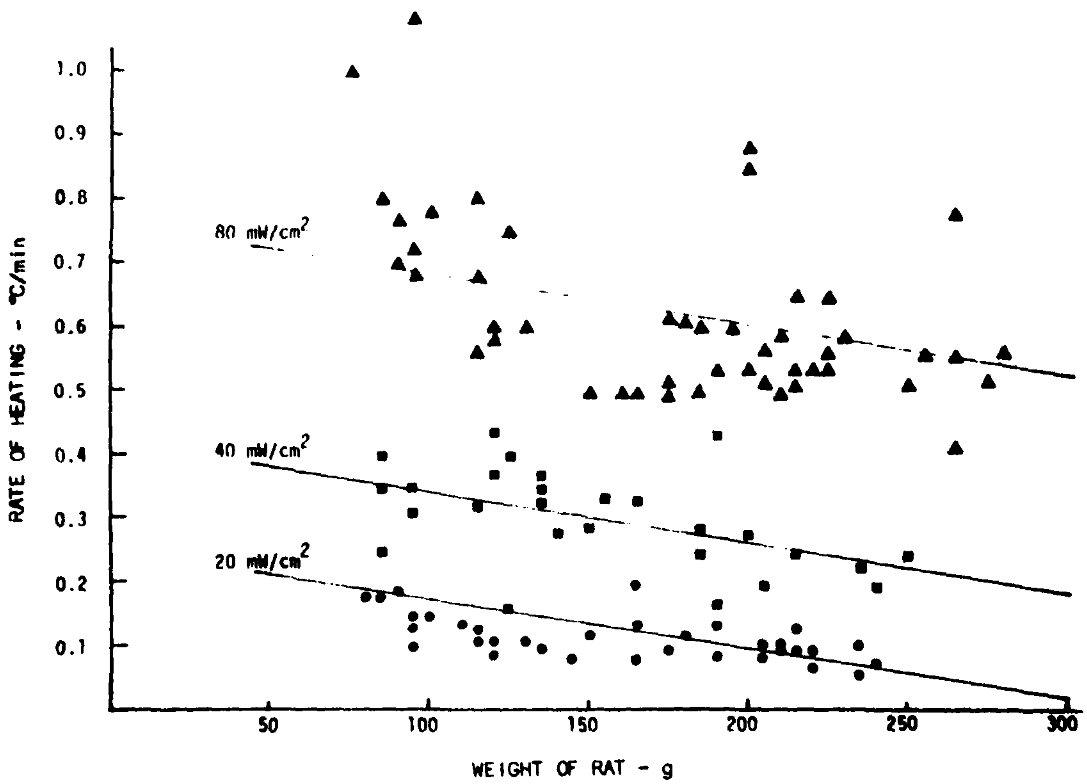

Figure 2. Rate of heating in rats as a function of animal weight and incident power density at 1.2 GHz, CW, far field, E-polarization. Lines through data are from linear regression model. See Table 4 for details on model used.

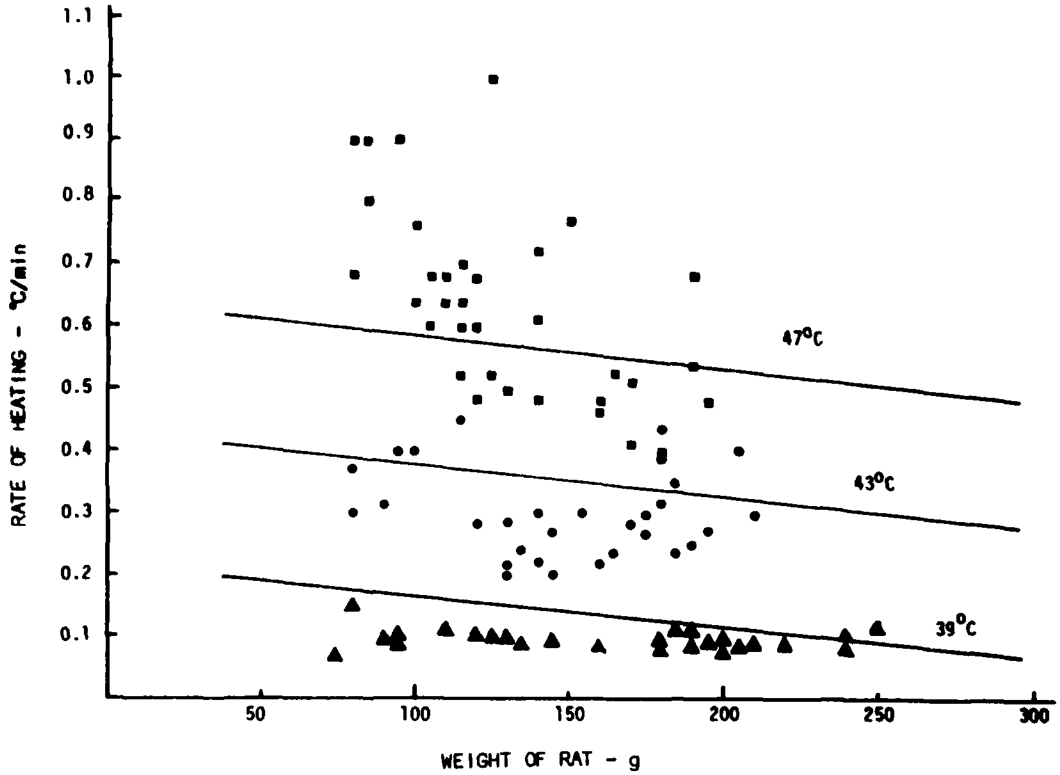

Figure 3. Rate of heating in rats as a function of animal weight and chamber dry bulb temperature at 90% RH. Lines through data are from linear regression model. See Table 4 for details on model.

Since the purpose of these experiments was to determine the equivalent moist heat exposure for a given RFR exposure, the selected models for RFR exposure and moist heat exposure were equated and solved to find the relationship between dry bulb temperature at 90% RH, RF power density, and animal weight. This equation is

$$\text{Dry Bulb Temp at 90\% RH} = \frac{1.893 + .00843\ \text{Power} - .000257\ \text{Wt}}{.0521}$$

This relationship is graphically displayed in Figure 4. Knowing the weight of the RFR-exposed rat and the RFR power density, the dry bulb temperature at 90% RH (for a rat of the same size) can be determined which will result in the same rate of internal body heating.

To simulate the maximum heating, the animal's rectal temperature is monitored during moist heating and the animal removed when its rectal temperature reaches the maximum RFR temperature required. A summary of the procedures to be used to simulate RFR heating is presented in Table 5.

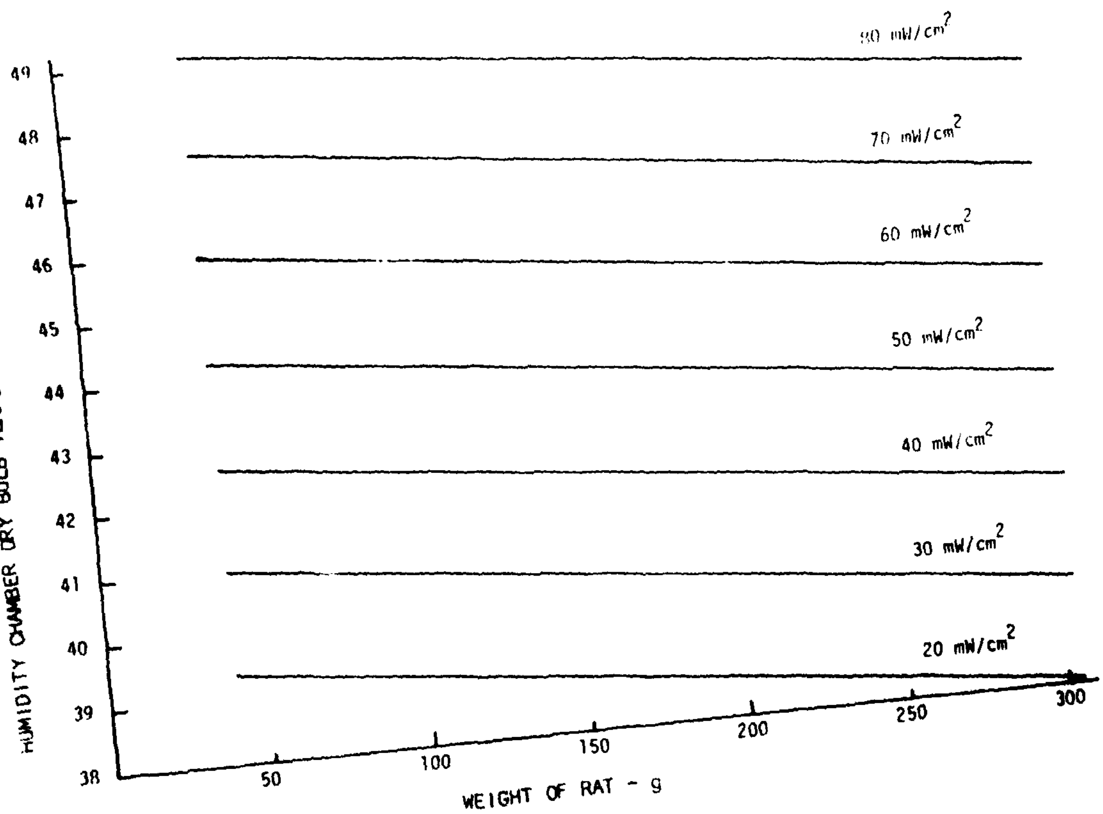

Figure 4. Humidity chamber dry bulb temperature as a function of animal weight and incident power density at 1.2 GHz, CW, far field. Graph is used to determine the equivalent rate of heating in the rat from moist heat and RFR heating.

TABLE 2. EXPERIMENTAL DATA FOR RFR EXPOSURES

Power density (mW/cm^2)	Animal weight (g)	RF slope (°C/min)
10	80.0	0.10
	85.0	0.09
	85.0	0.06
	95.0	0.05
	105.0	0.01
	110.5	0.03
	115.0	0.06
	120.0	0.04
	125.0	0.05
	130.0	0.03
	130.0	0.06
	135.0	0.07
	135.0	0.07
	140.0	0.07
	145.0	0.04
	150.0	0.07
	160.0	0.04
	165.0	0.03
	165.0	0.03
	175.0	0.08
	175.0	0.02
	175.0	0.12
	180.0	0.04
	185.0	0.02
	205.0	0.08
	210.0	0.09
	210.0	0.06
	210.0	0.05
	210.0	0.04
	215.0	0.04
	220.0	0.08
	225.0	0.06
	230.0	0.05
	240.0	0.05
	240.0	0.06
20	80.0	0.18
	85.0	0.18
	90.0	0.19
	95.0	0.13
	95.0	0.15
	95.0	0.10
	100.0	0.15
	110.0	0.14
	115.0	0.13

TABLE 2 (Continued)

Power density (mW/cm^2)	Animal weight (g)	RF slope (°C/min)
20 (Contd.)	115.0	0.11
	115.0	0.11
	120.0	0.09
	120.0	0.11
	130.0	0.11
	135.0	0.10
	145.0	0.08
	150.0	0.12
	165.0	0.08
	165.0	0.14
	165.0	0.20
	175.0	0.10
	175.0	0.10
	180.0	0.12
	190.0	0.09
	190.0	0.14
	205.0	0.11
	205.0	0.09
	210.0	0.10
	210.0	0.10
	210.0	0.11
	215.0	0.13
	215.0	0.10
	220.0	0.10
	220.0	0.07
	235.0	0.06
	235.0	0.11
	240.0	0.08
40	85.0	0.25
	85.0	0.35
	85.0	0.40
	85.0	0.40
	95.0	0.31
	95.0	0.35
	115.0	0.32
	120.0	0.44
	125.0	0.40
	125.0	0.16
	155.0	0.34
	135.0	0.37
	135.0	0.33
	135.0	0.35
	140.0	0.28
	150.0	0.29
	165.0	0.33
	185.0	0.29

TABLE 2 (Continued)

Power density (mW/cm2)	Animal weight (g)	RF slope (°C/min)
40 (Contd.)	185.0	0.25
	190.0	0.44
	190.0	0.17
	200.0	0.28
	205.0	0.20
	215.0	0.25
	235.0	0.23
	240.0	0.20
	250.0	0.25
	120.0	0.37
80	75.0	1.00
	85.0	0.79
	85.0	0.80
	90.0	0.77
	90.0	0.70
	95.0	0.68
	95.0	1.08
	95.0	0.72
	100.0	0.78
	115.0	0.56
	115.0	0.80
	115.0	0.68
	120.0	0.58
	120.0	0.60
	125.0	0.75
	130.0	0.60
	150.0	0.50
	160.0	0.50
	165.0	0.50
	175.0	0.50
	175.0	0.52
	175.0	0.62
	180.0	0.61
	185.0	0.60
	185.0	0.50
	190.0	0.53
	190.0	0.54
	190.0	0.54
	195.0	0.60
	200.0	0.85
	200.0	0.88
	200.0	0.54
	205.0	0.52
	205.0	0.57
	210.0	0.50
	210.0	0.59

TABLE 2 (Continued)

Power density (mW/cm^2)	Animal weight (g)	RF slope (°C/min)
80 (Contd.)	215.0	0.54
	215.0	0.52
	215.0	0.65
	220.0	0.54
	225.0	0.65
	225.0	0.54
	225.0	0.56
	230.0	0.59
	250.0	0.51
	250.0	0.52
	255.0	0.56
	265.0	0.78
	265.0	0.42
	265.0	0.56
	275.0	0.52
	280.0	0.57

TABLE 3. EXPERIMENTAL DATA FOR MOIST HEAT EXPOSURES

Dry bulb temperature (°C)	Animal weight (g)	Moist heat slope (°C/min)
34	255.0	0.050
	240.0	0.020
	225.0	0.020
	220.0	0.040
	215.0	0.040
	210.0	0.030
	210.0	0.030
	205.0	0.040
	195.0	0.030
	195.0	0.035
	190.0	0.060
	190.0	0.020
	170.0	0.050
	160.0	0.025
	160.0	0.035
	160.0	0.025
	160.0	0.025
	155.0	0.030
	155.0	0.040
	150.0	0.025
	135.0	0.020
	125.0	0.035
	120.0	0.030
	120.0	0.030
	110.0	0.035
	110.0	0.035
	110.0	0.040
	105.0	0.015
	85.0	0.020
	95.0	0.030
	85.0	0.030
	80.0	0.025
	80.0	0.030
	75.0	0.040
37	200.0	0.065
	220.0	0.050
	195.0	0.070
	195.0	0.050
	180.0	0.060
	180.0	0.065
	180.0	0.060
	170.0	0.065
	170.0	0.040

TABLE 3 (Contd.)

Dry bulb temperature (°C)	Animal weight (g)	Moist heat slope (°C/min)
37 (Contd.)	165.0	0.060
	160.0	0.060
	150.0	0.055
	145.0	0.060
	130.0	0.080
	130.0	0.085
	100.0	0.060
	95.0	0.070
	85.0	0.065
	90.0	0.050
	90.0	0.080
	90.0	0.045
38	200.0	0.060
	190.0	0.060
	190.0	0.070
	190.0	0.080
	180.0	0.060
	185.0	0.060
	185.0	0.090
	180.0	0.080
	180.0	0.080
	175.0	0.075
	175.0	0.060
	170.0	0.070
	170.0	0.055
	160.0	0.070
	155.0	0.080
	155.0	0.085
	155.0	0.060
	150.0	0.065
	150.0	0.075
	150.0	0.055
	150.0	0.065
	140.0	0.065
	140.0	0.070
	140.0	0.055
	135.0	0.080
39	255.0	0.120
	240.0	0.085
	240.0	0.100
	225.0	0.090
	220.0	0.090
	210.0	0.090

TABLE 3 (Contd.)

Dry bulb temperature (°C)	Animal weight (g)	Moist heat slope (°C/min)
39 (Contd.)	205.0	0.080
	200.0	0.100
	200.0	0.070
	195.0	0.090
	195.0	0.090
	190.0	0.080
	190.0	0.100
	190.0	0.085
	190.0	0.110
	185.0	0.110
	185.0	0.110
	180.0	0.100
	180.0	0.080
	180.0	0.100
	180.0	0.090
	160.0	0.080
	145.0	0.090
	135.0	0.085
	135.0	0.085
	130.0	0.100
	125.0	0.095
	120.0	0.100
	110.0	0.110
	95.0	0.100
	95.0	0.080
	90.0	0.095
	90.0	0.095
	80.0	0.150
	75.0	0.070
40	275.0	0.100
	220.0	0.120
	220.0	0.130
	205.0	0.095
	180.0	0.105
	180.0	0.100
	170.0	0.135
	160.0	0.110
	160.0	0.150
	125.0	0.125
	120.0	0.140
	120.0	0.125
	95.0	0.130
	90.0	0.150
	90.0	0.150

TABLE 3 (Contd.)

Dry bulb temperature (°C)	Animal weight (g)	Moist heat slope (°C/min)
40 (Contd.)	85.0	0.145
	85.0	0.160
42	210.0	0.100
	210.0	0.110
	200.0	0.130
	180.0	0.130
	180.0	0.105
	175.0	0.125
	175.0	0.100
	170.0	0.120
	170.0	0.100
	140.0	0.120
	135.0	0.140
	130.0	0.110
	125.0	0.095
	120.0	0.140
	120.0	0.120
	120.0	0.140
	115.0	0.110
	115.0	0.145
	115.0	0.140
	115.0	0.135
	110.0	0.125
	110.0	0.150
	110.0	0.130
	105.0	0.115
	100.0	0.110
	100.0	0.110
	95.0	0.125
	90.0	0.160
	85.0	0.100
	80.0	0.110
	80.0	0.130
43	100.0	0.400
	95.0	0.400
	90.0	0.310
	80.0	0.300
	80.0	0.370
	80.0	0.360
	160.0	0.220
	155.0	0.300
	145.0	0.200
	145.0	0.270

TABLE 3 (Contd.)

Dry bulb temperature (°C)	Animal weight (g)	Moist heat slope (°C/min)
43 (Contd.)	145.0	0.260
	140.0	0.220
	140.0	0.300
	135.0	0.240
	130.0	0.280
	130.0	0.220
	130.0	0.200
	120.0	0.280
	210.0	0.300
	205.0	0.400
	195.0	0.270
	190.0	0.250
	185.0	0.350
	185.0	0.240
	180.0	0.440
	180.0	0.390
	180.0	0.320
	180.0	0.320
	175.0	0.300
	175.0	0.270
	170.0	0.280
	170.0	0.290
	170.0	0.270
	170.0	0.430
	170.0	0.300
	165.0	0.240
	165.0	0.320
	115.0	0.450
44	245.0	0.270
	250.0	0.320
	240.0	0.320
	240.0	0.300
	235.0	0.360
	230.0	0.300
	230.0	0.430
	225.0	0.500
	220.0	0.420
	215.0	0.440
	210.0	0.400
	200.0	0.340
	195.0	0.380
	190.0	0.430
	180.0	0.280
	185.0	0.450

TABLE 3 (Contd.)

Dry bulb temperature (°C)	Animal weight (g)	Moist heat slope (°C/min)
44 (Contd.)	180.0	0.390
	180.0	0.380
	180.0	0.460
	180.0	0.380
	175.0	0.380
	175.0	0.300
	165.0	0.360
	140.0	0.420
	140.0	0.420
	140.0	0.420
	140.0	0.400
	135.0	0.440
	135.0	0.400
	90.0	0.320
	90.0	0.560
	90.0	0.540
	90.0	0.420
	85.0	0.440
	80.0	0.510
	80.0	0.450
	80.0	0.600
	80.0	0.440
45	125.0	0.400
	90.0	0.500
	75.0	0.740
	240.0	0.420
	230.0	0.460
	225.0	0.500
	215.0	0.360
	210.0	0.380
	200.0	0.380
	200.0	0.470
	195.0	0.420
	185.0	0.480
	160.0	0.580
	160.0	0.560
	160.0	0.560
	150.0	0.460
	140.0	0.490
	140.0	0.400
	140.0	0.520
47	195.0	0.480
	190.0	0.680

TABLE 3 (Contd.)

Dry bulb temperature (°C)	Animal weight (g)	Moist heat slope (°C/min)
47 (Contd.)	190.0	0.540
	180.0	0.440
	180.0	0.400
	180.0	0.240
	170.0	0.510
	170.0	0.410
	165.0	0.520
	160.0	0.460
	160.0	0.480
	150.0	0.770
	140.0	0.720
	140.0	0.610
	140.0	0.480
	135.0	0.210
	130.0	0.500
	125.0	0.520
	125.0	0.900
	120.0	0.480
	120.0	0.600
	120.0	0.680
	115.0	0.520
	115.0	0.600
	115.0	0.640
	115.0	0.700
	110.0	0.640
	110.0	0.680
	110.0	0.680
	105.0	0.680
	105.0	0.600
	100.0	0.640
	100.0	0.760
	100.0	0.640
	95.0	0.800
	85.0	0.700
	85.0	0.800
	80.0	0.680
	80.0	0.800
48	235.0	0.570
	210.0	0.490
	205.0	0.640
	195.0	0.540
	190.0	0.700
	190.0	0.600
	185.0	0.660

TABLE 3 (Contd.)

Dry bulb temperature (°C)	Animal weight (g)	Moist heat slope (°C/min)
48 (Contd.)	180.0	0.540
	170.0	0.520
	165.0	0.600
	165.0	0.650
	160.0	0.660
	170.0	0.860
	165.0	0.540
	160.0	0.500
	155.0	0.700
	150.0	0.750
	150.0	0.580
	150.0	0.580
	145.0	0.600
	225.0	0.580
	135.0	0.620
	130.0	0.760
	130.0	0.700
	190.0	0.600
	120.0	0.800
	115.0	0.820
	185.0	0.530
	105.0	0.800
	135.0	0.800
	105.0	1.000
	100.0	0.680
	100.0	0.760
	100.0	0.820
	100.0	0.820
	100.0	0.680
	95.0	0.700
	95.0	0.710
	85.0	0.600
	85.0	0.780
49	225.0	0.560
	225.0	0.520
	225.0	0.640
	225.0	0.680
	220.0	0.600
	220.0	0.560
	220.0	0.680
	210.0	0.640
	205.0	0.680
	195.0	0.680
	185.0	0.680

TABLE 3 (Contd.)

Dry bulb temperature (°C)	Animal weight (g)	Moist heat slope (°C/min)
49 (Contd.)	180.0	0.640
	170.0	0.620
	170.0	0.600
	170.0	0.560
	170.0	0.620
	175.0	0.820
	165.0	0.620
	165.0	0.800
	165.0	0.660
	160.0	0.600
	155.0	0.760
	155.0	0.800
	155.0	0.680
	150.0	0.600
	145.0	0.500
	145.0	0.520
	145.0	0.680
	140.0	0.600
	135.0	0.640
	135.0	0.680
	130.0	0.500
	125.0	0.680
	125.0	0.720
	125.0	0.760
	120.0	0.860
	100.0	0.940
	100.0	0.680
	100.0	0.820
	95.0	0.560
	90.0	0.600
	90.0	0.560
	90.0	0.700
	90.0	0.820
	90.0	0.720
	90.0	0.640
	85.0	0.900
	85.0	0.680
	75.0	0.540
	75.0	0.760
50	235.0	0.880
	245.0	0.640
	240.0	0.900
	230.0	0.740
	225.0	0.980

TABLE 3 (Contd.)

Dry bulb temperature (°C)	Animal weight (g)	Moist heat slope (°C/min)
50 (Contd.)	220.0	0.800
	220.0	0.840
	215.0	0.720
	210.0	0.700
	210.0	0.620
	210.0	0.800
	195.0	0.700
	190.0	0.900
	185.0	0.640
	175.0	0.820
	170.0	0.560
	160.0	0.830
	160.0	0.770
	160.0	0.620
	140.0	0.700
	130.0	0.840
	130.0	0.760
	125.0	0.920
	125.0	0.820
	115.0	0.760
	120.0	0.930
	80.0	0.620
	80.0	0.780
	75.0	1.260
	75.0	0.850
	120.0	0.920

TABLE 4. RESULTS OF STATISTICAL ANALYSIS

Analysis of RFR exposures

Factors in the model	R
Power, Wt	.951*
Power, $(Power)^2$, Wt	.951
Power, $(Power)^2$, $(Power)^3$, Wt	.952
Power, $(Power)^2$, Power*Wt, Wt	.957
Power, Power*Wt	.956
Wt	.008

*Selected model

RF Slope = .0838 - .0007628 Wt + .00843 Power

Std error = .07962   df = 149

Analysis of moist heat exposures

Factors in the model	R
Temp, Wt	.916*
Temp, $(Temp)^2$, Wt	.939
Temp, $(Temp)^2$, $(Temp)^3$, Wt	.943
Wt, $(Wt)^2$, Temp, $(Temp)^2$, Wt*Temp	.943

*Selected model

Heat Slope = -1.8092 - .000505 Wt + .0521 Temp

Std error = .11251   df = 416

TABLE 5. PROCEDURE FOR SIMULATING RFR EXPOSURES IN RAT AT 1.2 GHz, E-FIELD ORIENTED

1. Select rat for use, determine weight, place in cylindrical Plexiglas holder, insert temperature probe 2 cm into rectum.

2. Place animal in anechoic chamber parallel to E-field and allow to stabilize for 10 min before exposure.

3. Expose rat to 1.2 GHz, far field, at desired RFR power density.

4. Record temperature profile of rat during exposure.

5. Remove rat and perform desired biological assay.

6. Refer to Figure 4 of this report; knowing the power density and weight of the animal, the dry bulb temperature at 90% RH can be determined.

7. Set "Vapor-Temp," controlled relative humidity chamber for that dry bulb temperature and 90% RH and allow to stabilize.

8. Select a rat of the identical weight as the RFR exposure, place in same cylindrical Plexiglas holder, and insert temperature probe 2 cm into rectum.

9. Allow rat to stabilize for 10 min at room temperature, insuring that the room temperature is the same as the anechoic chamber temperature.

10. Place rat in "Vapor-Temp" and record the rectal temperature profile.

11. Remove rat from "Vapor-Temp" when animal's rectal temperature reaches the maximum temperature seen in the RFR exposure.

12. Perform the desired biological assay.

CONCLUSIONS

A method for simulating RFR heating in rats at 1.2 GHz, E-field oriented, has been developed. This procedure can adequately simulate the linear rate of internal heating (after physiological cooling mechanisms react) and the peak temperature excursion but lacks the capability to simulate the rapid initial rate of temperature rise due to RFR.

The effect of this shortcoming is not clear, and may well vary with the type of end point being measured. Recognizing the unique early response to RFR heating, the moist heat method appears to be preferable to using dry heat to simulate RFR heating.

Results reported here are for a specific set of exposure parameters that may not be applicable for other frequencies or species of experimental animals.

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